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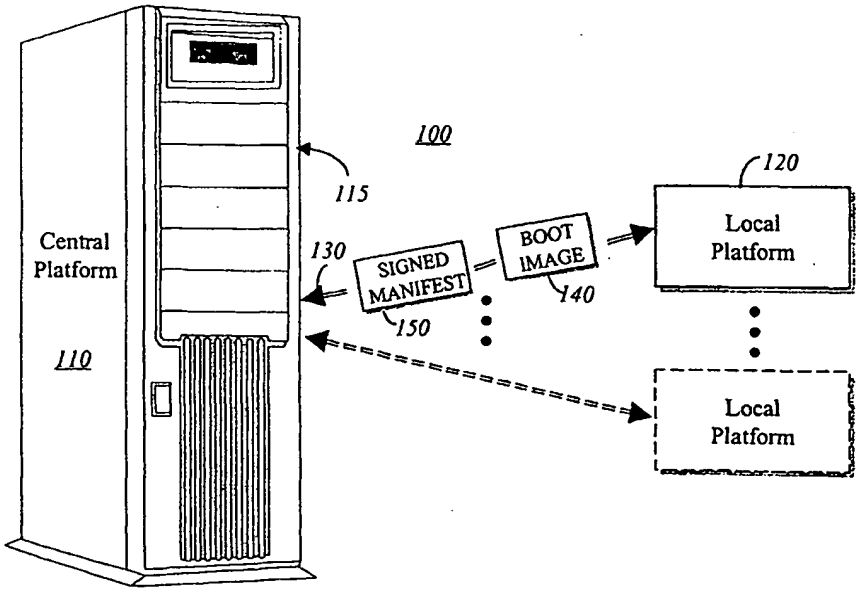

(57) Abstract

A method to verify integrity of information (140) and selectively determine whether the information is authorized to be executed by the platform. The information is downloaded to a platform (120) operating in a pre-boot operational state.

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A SYSTEM AND METHOD FOR VERIFYING THE INTEGRITY AND AUTHORIZATION OF SOFTWARE BEFORE EXECUTION IN A LOCAL PLATFORM

BACKGROUND

1. Field

The present invention relates to the field of data security. More particularly, this invention relates to a scheme for verifying the integrity of downloaded software to a platform during its pre-boot operations and selectively authorizing execution of the software.

2. General Background

Computers have become an important product for both commercial and personal use, in part due to their versatility. While the purchase price of computers has decreased over the last few years, the total cost of computer ownership has remained generally constant. One reason is that computers require occasional maintenance to repair or replace faulty hardware, reconfigure corrupted software, or perform other tasks. Normally, computer technicians, at a substantial cost, perform these tasks.

Currently, many companies employ one or more on-site computer technicians to install, support and maintain stand-alone computers. In fact, large companies have established Information Technology (IT) departments that feature computer technicians responsible for servicing thousands of stand-alone computers situated in multiple facilities. Thus, a significant portion of the technician's working time is spent traveling from one job to another. To reduce overhead costs and improve efficiency, it is desirable to lessen the

amount of time wasted by computer technicians traveling between jobs or facilities. This can be accomplished by implementing a centralized platform with multiple disk drives from which employees can remotely access information as needed. As a result, the computer technicians can diagnose and service problems with the centralized platform (e.g., drive errors) at one location, and thus, greatly reduce the amount of travel time.

As centralized platforms are adopted by more and more companies, the general architecture of computers is likely to be altered to exclude disk drives, which are the least reliable component of a computer. This computer architecture alteration, however, poses a problem because most computers boot from a local disk drive.

To overcome this problem, a boot procedure of the computer may be modified so that boot software is downloaded over a network. In particular, during its boot sequence, the local platform would access a particular memory location on a disk drive remotely located at the centralized platform and retrieve a boot image from that memory location. The boot image would be downloaded into main memory of the computer and executed during the boot sequence. Unfortunately, there is currently no security scheme to ensure the integrity of the boot image (e.g., check that the software is free from viruses or has not been tampered with before or during download) as well as its authenticity (e.g., check that the boot image originated from its proper source). The present invention provides a scheme that overcomes these security flaws.

SUMMARY OF THE INVENTION

The present invention relates to a method for verifying integrity of information. The information is downloaded to a platform operating in a pre-boot operational state. Thereafter, a determination of whether the information is authorized to be executed by the platform is selectively performed.

BRIEF DESCRIPTION OF THE DRAWINGS

The features and advantages of the present invention will become apparent from the following detailed description of the present invention in which:

Figure 1 is a block diagram of an illustrative embodiment of a network including a central platform and one or more local platforms.

Figure 2 is a block diagram of an illustrative embodiment of a local platform.

Figure 3 is a block diagram of an illustrative embodiment of a digitally signed manifest downloaded from the central platform during the boot sequence of the local platform.

Figure 4 is a block diagram of an illustrative embodiment of the acts for creating the manifest digital signature.

Figures 5A and 5B are illustrative flowcharts of the acts performed to verify that the downloaded application has not been tampered with and the downloaded application is authorized to run on the local platform.

DETAILED DESCRIPTION

Herein, certain embodiments of the invention are described for verification of downloaded software to a local platform, operating in a pre-boot operational state, before execution of that software. For this illustrative embodiment, the "software" comprises an image of an application executed during the boot-up sequence of the local platform (herein referred to as a "boot image"). However, this embodiment should be broadly construed as illustrative in nature to merely represent the spirit of the invention. Furthermore, verification of the downloaded boot image confirms the integrity of the boot image (e.g., image has not been altered), and perhaps, that the image is authorized to run on the local platform.

Certain terminology is used to describe various embodiments of the system architecture. A "platform" includes hardware whose functionality is dependent on software executed therein. Examples of a platform include, but are not limited or restricted to a computer (e.g., a laptop, desktop, hand-held, server, mainframe, etc.), imaging equipment (e.g., printer, facsimile machine, etc.), and a set-top box (cable box or network computer, etc.). A "link" includes one or more pathways for information to be routed. These pathways may be established through any type of medium such as electrical wire, fiber optics, cable, Plain Old Telephone System (POTS) lines, leased lines or even wireless communications. Also, information is considered "downloaded" when acquired from a remote location and provided to the platform through a link or a removable storage device such as a floppy disk, compact disk, smart card, and the like.

With respect to cryptography related terminology, a "key" is an encoding and/or decoding parameter. In general, a "digital signature" includes digital data encrypted with a private key of its signatory. In some cases, digital data is provided in its entirety or in an encoded form produced by a one-way hash function. The digital signature is used to protect the integrity of data by avoiding its illicit modification and is used to identify the source of

data. A "digital certificate" is a message in a standardized format comprising (i) a public key of the source providing the software to the local platform (hereafter referred to as the "subject public key"), (ii) information (e.g., public key, code, serial number, etc.) to identify the issuer of the digital certificate, and (iii) a digital signature of the certificate produced with a private key of the issuer. Examples of an "issuer" include a manufacturer, a trade association, a governmental entity, a bank, a particular department of a company (e.g., security or the Information Technology "IT" department) or any other entity in a position of trust. A "digital certificate chain" includes an ordered sequence of multiple digital certificates arranged for authorization purposes as described below, where each successive certificate represents the issuer of the preceding certificate.

Referring now to Figure 1, an illustrative block diagram of an embodiment of a network 100 comprising a central platform 110 and one or more local platforms 120 is shown. In this embodiment, central platform 110 includes a server having at least one disk drive 115. Disk drive 115 is loaded with applications, where images of the applications are downloaded to a local platform 120 upon request. For example, during its pre-boot operational state, local platform 120 may request a boot image 140 to be downloaded over communication link 130 from central platform 110. Of course, boot image 140 may comprise one or more sub-images forming the entire boot image. To verify that boot image 140 is executable by local platform 120, a signed manifest 150 (see Figure 3) corresponding to boot image 140 is downloaded to local platform 120 generally concurrent in time with boot image 140. Of course, it is contemplated that signed manifest 150 may be downloaded preceding or subsequent to the transfer of boot image 140.

Referring to Figure 2, an illustrative block diagram of an embodiment of local platform 120 is shown. In this embodiment, local platform 120 comprises a chipset 200 coupled to a processor 210 and a memory 220 through a host bus 230 and a memory bus 240, respectively. In addition, chipset 200 is coupled to a bus 250 that provides a

pathway to one or more system resources 260. Herein, bus 25C comprises a multiplexed bus (e.g., Peripheral Component Interconnect "PCI" bus); however, any other type of bus architecture (e.g., Industry Standard Architecture "ISA") or combination of bus architectures may be used. For example, bus 250 is shown as a single bus, but it is contemplated that bus 250 may include multiple buses coupled together through bridge circuitry. For that embodiment, system resources 260 would be coupled to at least one of the multiple buses.

As shown, system resources 260 comprise a communication device 260_1 and a persistent storage device 260_2. Communication device 260_1 is configured to establish communications with central platform 110 over communication link 130 of Figure 1. Examples of communication device 260_1 include a network interface card, a modem card or an external modem. Persistent storage device 260_2 includes, for example, a programmable, non-volatile memory such as flash memory, battery-backed random access memory (RAM), and the like.

Prior to the local platform undergoing a boot procedure, persistent storage device 260_2 is provided with a verification function 270, an authorization certificate 280 and an authorization check enable flag 290. It is contemplated that this information may be protected against unauthorized modification by a number of techniques. For example, processor 210 may be set to trap and disallow memory-write accesses within an address range, or chipset 200 may be set to provide a one-way write-protect to a memory address range during an earlier phase of the boot procedure. Other techniques that may be used include (i) configuring persistent storage device 260_2 to be non-responsive to memory-write accesses; (ii) providing a software interface requiring user authentication to update the contents of persistent storage device 260_2; and (iii) implementing various materials or circuitry to attempt to detect physical tampering to the persistent storage device 260_2, which would then render the local platform inoperable.

In this embodiment, as further shown in detail in Figures 5A and 5B, verification function 270 includes software, executed by the local platform during pre-boot, in order to perform an integrity check procedure. The integrity check procedure verifies that a boot image has not been modified since the signed manifest was created. Thus, modifications to the boot image can be detected while the boot image is stored locally or at the central platform, or when in transit to the local platform. As an optional feature, the verification function 270 further performs an authorization check procedure to determine whether the boot image has been provided by an acceptable source. The authorization check procedure is performed when authorization check enable flag 290 is enabled.

Since the central platform actually determines which boot image(s) is (are) authorized to be downloaded to the local platform, only a single configuration parameter, authorization certificate 280, is installed into local platform 120. This reduces the cost of maintaining many different types of local platform configurations. More specifically, the installation of authorization certificate 280 provides a public key of a source (e.g., person, company, etc.) authorized to provide the boot image. Confirmation on whether or not the source is authorized to provide the image is determined through analysis of the signed manifest using the public key provided by authorization certificate 280. It is contemplated that multiple authorization certificates may be implemented in persistent storage device 260_2 when it is desirable for different, unrelated sources to authorize boot images to run on the local platform.

Referring to Figure 3, an illustrative block diagram of signed manifest 150 corresponding to boot image 140 is shown. Signed manifest 150 includes (i) a secure hash value 300 for each sub-image of the boot image, (ii) a manifest digital signature 310, and (iii) a certificate chain 320 providing the identify of the signatory of signed manifest 150 and those entities which have bestowed signing authority to the signatory. Each secure hash value 300 is produced by loading a corresponding sub-image into a one-way hash function that converts the portions of the boot image into information of a fixed length

("hash value"). The term "one-way" indicates that there does not readily exist an inverse function to recover any discernible portion of the boot image from the hash value.

As shown in Figure 4, in this embodiment, manifest digital signature 310 is produced by initially appending M hash values 300 end-to-end (where "M" is a positive whole number, M≥1) to provide a hash set 330. Thereafter, hash set 330 is digitally signed with a private key (PRKS) of the source authorized to provide the boot image. Herein, the functions used for digitally signing information include Rivest Shamir Adleman (RSA) by RSA Data Security, Inc. of Redwood City, California and the Digital Signature Algorithm (DSA) proposed by the National Institute of Standards. Both of these functions are described in pages 466-494 of a publication entitled Applied Cryptography - Protocols, Algorithms and Source Code in C by Bruce Schneier, published by John Wiley & Sons, Inc. (1996).

Referring back to Figure 3, certificate chain 320 includes a set of "R" digital certificates, where "R" is a positive whole number (R≥1). A first digital certificate 320_1 (referred to as "certificate[1]") includes a subject public key of the signatory, namely the source responsible for digitally signing the signed manifest 150. Thereafter, the remaining "R-1" digital certificates collectively provide a sequence of those sources issuing the first digital certificate 320_1 used to sign the signed manifest 150. For example, a second digital certificate 320_2 (referred to as "certificate[2]") includes the subject public key of the source that signed certificate[1] using the corresponding private key of that source.

The use of certificate chain 320 provides the ability to delegate signing authority from one source to another. The signatory of the signed manifest is accepted as an authorized signatory when one of the certificates in certificate chain 320, for example, certificate[K], where "K" is a positive whole number (1≤K≤R), includes a subject public key matching the subject public key in the authorization certificate 280. Also, for each certificate[N] in the certificate chain 320, where "N" is a positive whole number (1≤N<K),

certificate[N] verifies with the subject public key of certificate[N+1] in the certificate chain 320. An authorized source delegates authorization to a signatory by providing an unbroken sequence of certificates between the authorized source and the signatory.

Referring now to Figures 5A and 5B, illustrative flowcharts are shown outlining the acts performed to verify the integrity of downloaded software, namely that the software has not been modified and is authorized to run on the local platform. Upon retrieving a boot image, the verification function is invoked and given references associated with the boot image (block 500). In this embodiment, the "references" include address pointers to data structures associated with both a data object (e.g., an in-memory copy of the boot image awaiting verification) and an optional signed manifest. Each of these data structures comprise (i) a physical address pointer to a contiguous block of memory and (ii) a length in bytes.

Upon being invoked, the verification function verifies the boot image. If the application image can be executed by the local platform, the verification function returns a SUCCESS signal value (blocks 505, 535, 565 and 580). Otherwise, verification function returns a FAILURE signal value to indicate that the boot image cannot be executed by the local platform (blocks 515, 530, 560, 590 and 600). Of course, it is contemplated that the verification function automatically returns a SUCCESS signal value when no signed manifest accompanies the boot image when downloaded to the local platform and no authorization check procedure is required or performed (block 505). As a result, no integrity check procedure is performed as well.

However, if the reference of the signed manifest is accessible by the verification function, the manifest digital signature is verified by using the subject public key from certificate[1] of the signed manifest (block 510). For example, this may be accomplished by decrypting the manifest digital signature with the subject public key and comparing the result with a secure hash value computed for the signed data. If the manifest digital

signature does not verify properly, the verification function returns a FAILURE signal value (block 515). Otherwise, as shown in blocks 520-525, a hash value of the downloaded boot image is calculated and compared with the secure hash value contained in the signed manifest. If a match is not detected, the verification function returns a FAILURE signal value that causes the network boot procedure to fail (block 530).

Next, the verification function determines whether the authorization check procedure is desired (block 540). This is accomplished by determining whether the authorization check enable flag is enabled. If not, the verification function returns a SUCCESS signal value, indicative that the boot image is executable by the local platform, because the data integrity check procedure has successfully completed (block 535). Otherwise, the verification function undergoes the authorization check procedure described in Figure 5B.

The authorization check procedure is to ensure that the source of the signed manifest signature has been authorized. This is accomplished by confirming the validity of the certificate chain contained in the signed manifest. For example, as shown in Figure 5B, a determination is made whether the authorization certificate has been pre-loaded in a persistent storage device (block 550). If not, a determination is made whether the user has authorized the image (block 555). Such authorization may be accomplished, for example, by asking the user to compare a hash of the boot image against a known "good" hash value. If the user authorizes the image, the verification function returns a SUCCESS signal value to continue the network boot procedure (block 565). Otherwise, the verification function returns a FAILURE signal value (block 560).

In the event that one or more authorization certificates have been pre-loaded into a persistent storage device, a count value (CNT) is set to a predetermined number (e.g., CNT=1) and a determination is made whether a public key of the signatory, found in certificate[CNT], matches the public key of any of the authorization certificate(s) (blocks

570-575). If so, the verification function returns a SUCCESS signal value representing that the boot image is authorized to run on the local platform (block 580). If no match is detected, a determination is made as to whether CNT<R (number of certificates in the certificate chain) to check whether or not each digital certificate has been checked (block 585). If CNT≥R, the verification function returns a FAILURE signal value, preventing the boot image from being run on the local platform (block 590). However, if CNT<R, a determination is made whether the digital signature contained in certificate[CNT] verifies using the public key of certificate[CNT+1] (block 595). If not, the verification function returns a FAILURE signal value preventing the boot image from being run on the local platform (block 600). However, if the verification of certificate[CNT] using the public key of certificate[CNT+1] was successful, CNT is incremented (block 605) and blocks 575-605 are repeated for each certificate until a signal value is returned.

While certain exemplary embodiments have been described and shown in the accompanying drawings, it is to be understood that such embodiments are merely illustrative of and not restrictive on the broad invention, and that this invention not be limited to the specific constructions and arrangements shown and described, since various other modifications may occur to those ordinarily skilled in the art.

CLAIMS

What is claimed is:

1. A method comprising:

verifying integrity of information downloaded to a platform operating in a pre-boot operational state; and

selectively determining whether the information is authorized to be executed by the platform.

2. The method of claim 1, wherein prior to the integrity verification, the method further comprises

providing the information to the platform, the information includes a signed manifest and an image of a boot application normally executed by the platform during a boot procedure.

3. The method of claim 2, wherein the signed manifest includes a manifest digital signature, a secure hash value of the image of the boot application, and a certificate chain.

4. The method of claim 3, wherein the secure hash value includes a plurality of hash values having a one-to-one correspondence with a plurality of sub-images forming the image of the boot application.

5. The method of claim 3, wherein the manifest digital signature includes the secure hash value encrypted with a private key of a first source, the first source providing the image of the boot application to the local platform.

6. The method of claim 5, wherein the certificate chain includes a first digital certificate, the first digital certificate includes a public key of the first source, a public key of an issuer of the first digital certificate and a digital signature of the first digital certificate digitally signed by a second source.

7. The method of claim 6, wherein the certificate chain further includes a second digital certificate, the second digital certificate including a public key of the second source, a public key of an issuer of the second digital certificate and a digital signature of the second digital certificate digitally signed by a third source.

8. The method of claim 3, wherein the certificate chain includes a plurality of successive digital certificates of which a $R+1^{th}$ digital certificate includes a public key of a signatory of a digital signature in a R^{th} digital certificate, where R is a positive whole number.

9. The method of claim 5, wherein the integrity of the information is verified by (i) accessing the contents of a first digital certificate of the certificate chain to obtain a public key of the first source, (ii) verifying the manifest digital signature with the public key of the first source, (iii) accessing contents of the signed manifest to obtain the secure hash value, (iv) performing a hash operation on the image of the boot application in accordance with a predetermined hash function, used to produce the secure hash value, to produce a resultant hash value, and (v) comparing the secure hash value with the resultant hash value.

10. The method of claim 9, wherein the integrity of the information is deemed to be maintained if the secure hash value matches the resultant hash value.

11. The method of claim 3, wherein the selective determination of whether the information is authorized comprises:

accessing contents of a first digital certificate of the certificate chain;

comparing a subject public key within the first digital certificate with a public key of a signatory of the manifest digital signature; and

authorizing execution of the information if the subject public key matches the public key of the signatory.

12. A method for determining whether information is authorized to run on a platform, the method comprising:

providing a certificate chain including a plurality of digital certificates, each digital certificate includes a subject public key and a digital signature;

comparing a public key of an authorization certificate pre-loaded into the platform to a subject public key of a first digital certificate of the plurality of digital certificates; and

determining that the information is authorized to run on the platform if the public key of the authorization certificate matches the subject public key of the first digital certificate.

13. The method of claim 12 further comprising:

repeatedly verifying a previous digital certificate with the subject public key of a next successive digital certificate if the subject public key of the previous digital certificate fails to match the public key in the authorization certificate;

repeatedly comparing the public key of the authorization certificate to the subject public key of a next successive digital certificate if the subject public key of the previous digital certificate fails to match the public key in the authorization certificate;

determining that the information is authorized to run on the platform if the public key of the authorization certificate matches a subject public key of the remaining digital certificates; and

determining that the information is not authorized to run on the platform if the public key of the authorization certificate fails to match any of the plurality of subject public keys.

14. A platform comprising:

a processor; and

a persistent storage device in communication with the processor, the persistent storage device including

an authorization certificate including a public key of a source authorized to download a boot image to the platform, and

a verification function being software executed by the processor to verify whether the downloaded boot image has been modified.

15. The platform of claim 14, wherein the persistent storage device includes a flash memory.

16. The platform of claim 14, wherein the persistent storage device includes a battery backed random access memory.

17. The platform of claim 14, wherein the persistent storage device further includes an authorization check enable flag.

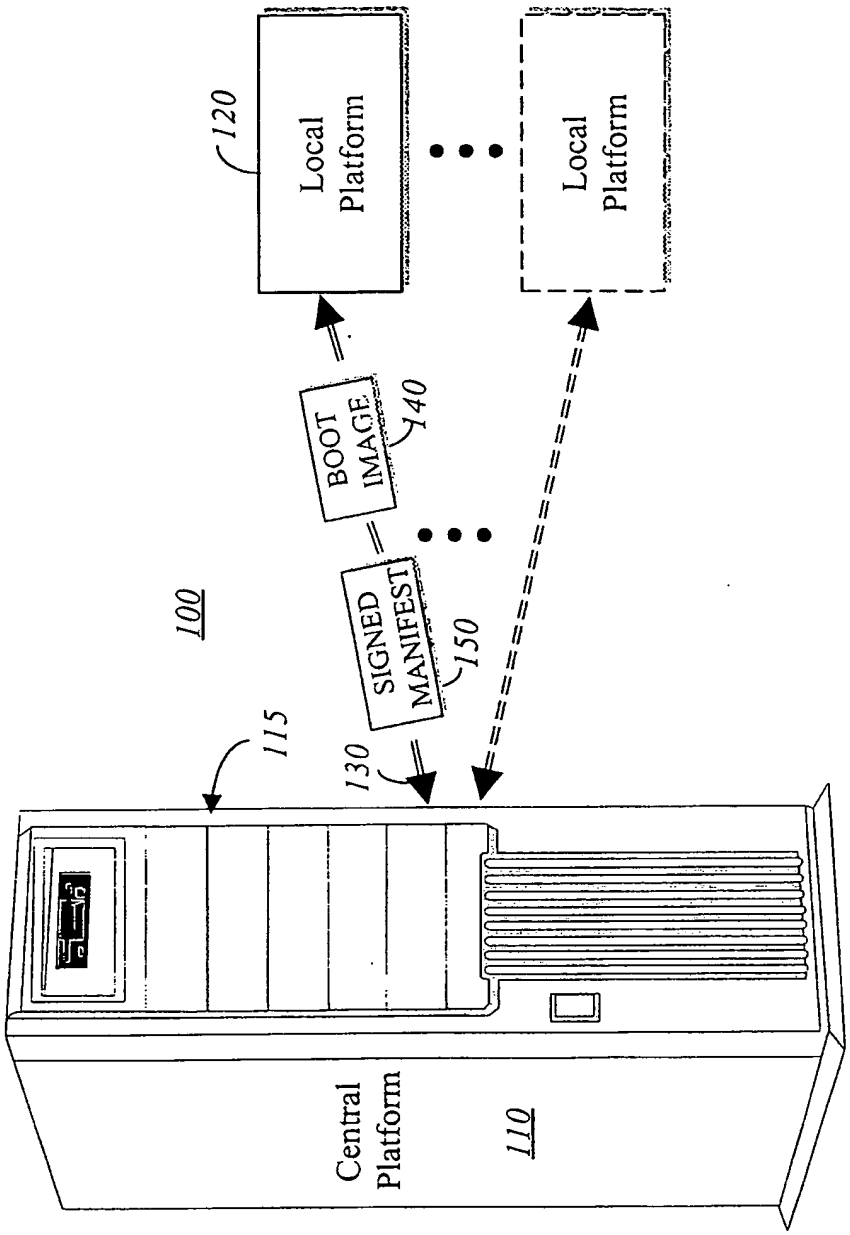
Local Platform
120
Local Platform
BOOT IMAGE
140
SIGNED MANIFEST
150
100
115
130
Central Platform
110

Figure 1

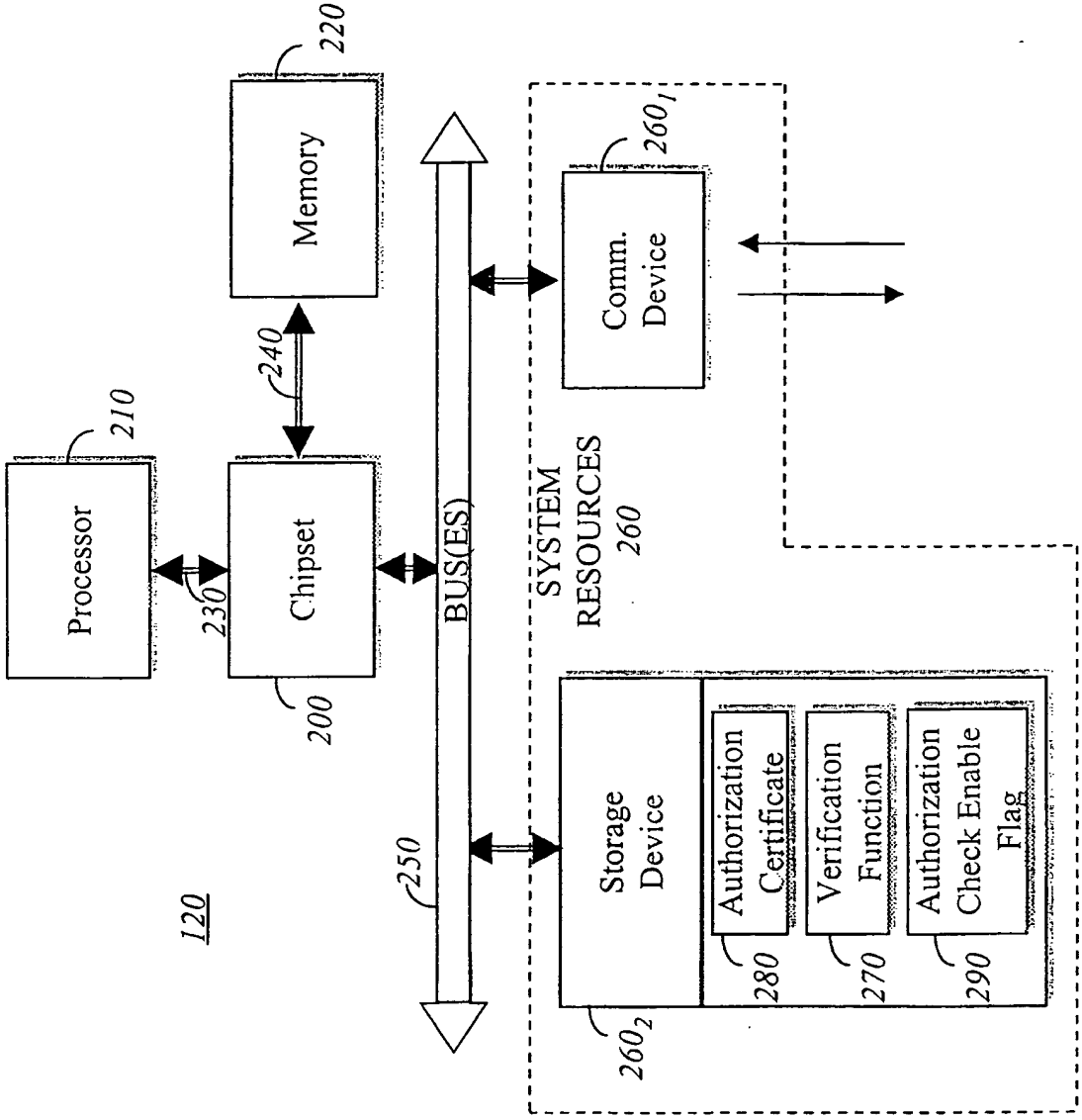
120
Processor
210
Chipset
200
230
240
Memory
220
BUS(ES)
250
SYSTEM RESOURCES
260
Comm. Device
260_1
Storage Device
260_2
Authorization Certificate
280
Verification Function
270
Authorization Check Enable Flag
290

Figure 2

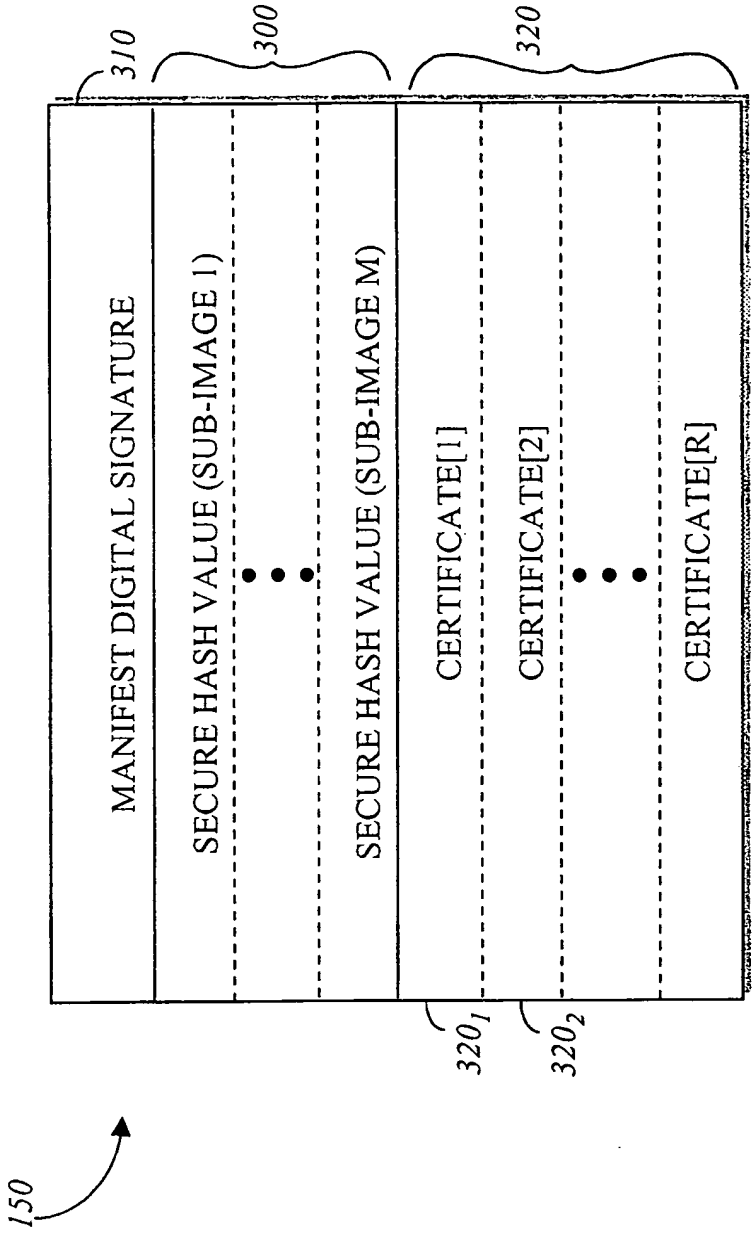
310
300
320
MANIFEST DIGITAL SIGNATURE
SECURE HASH VALUE (SUB-IMAGE 1)
SECURE HASH VALUE (SUB-IMAGE M)
CERTIFICATE[1]
CERTIFICATE[2]
CERTIFICATE[R]
320$_1$
320$_2$
150

Figure 3

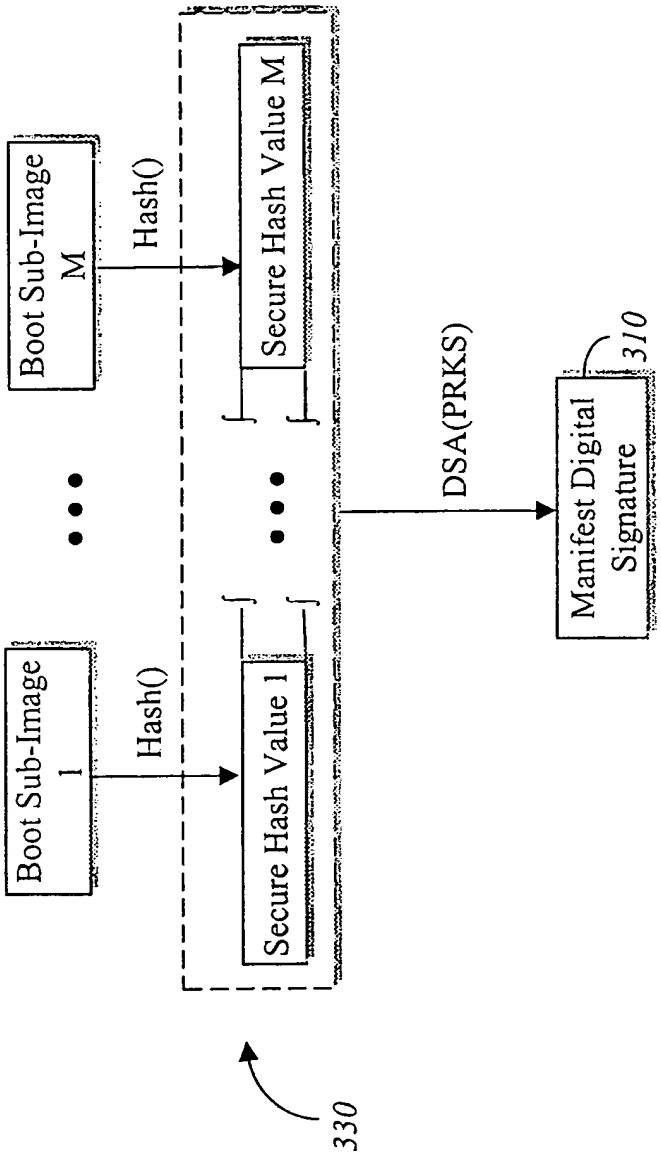
Boot Sub-Image 1
Hash()
Secure Hash Value 1
Boot Sub-Image M
Hash()
Secure Hash Value M
DSA(PRKS)
Manifest Digital Signature
310
330

Figure 4

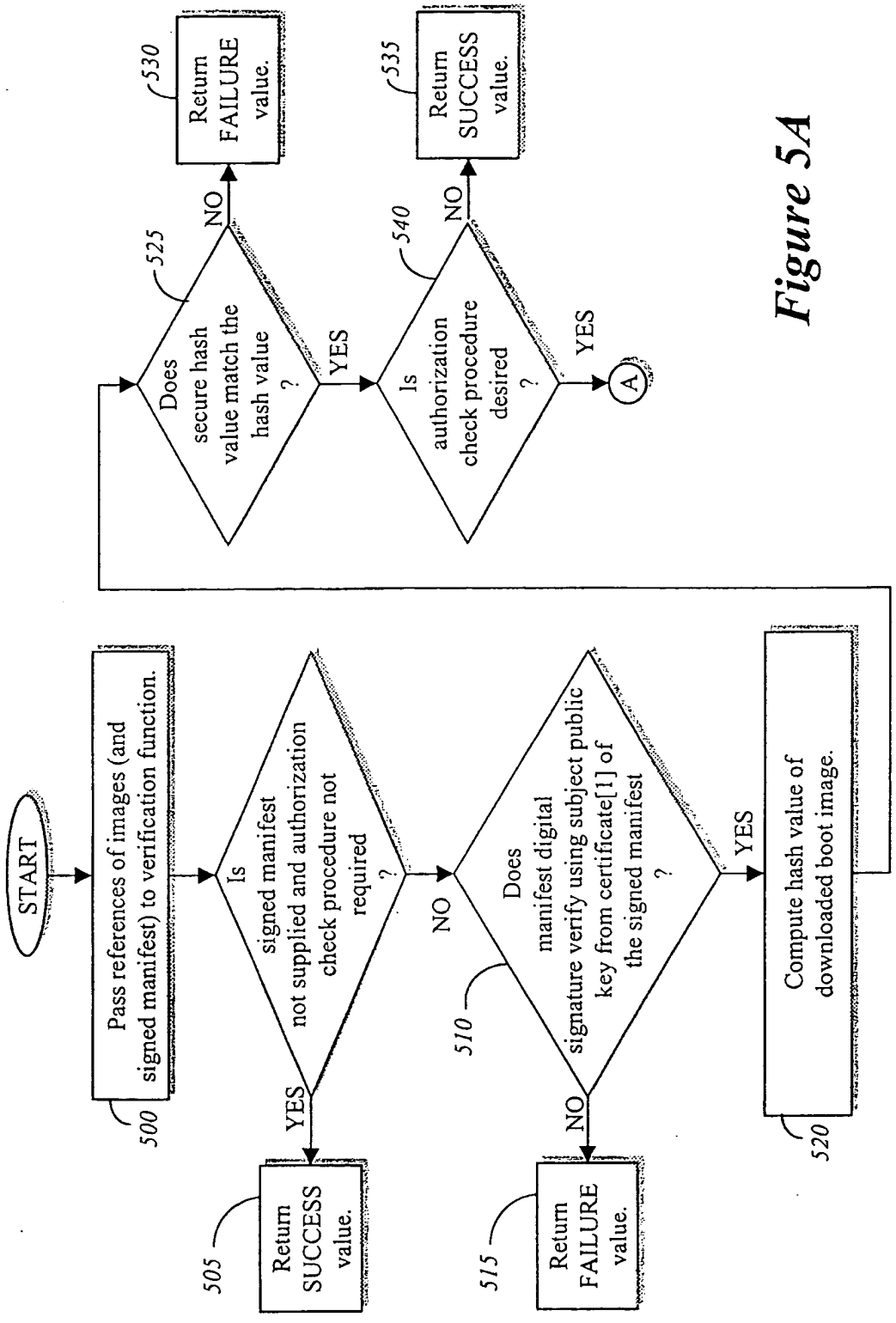
START
Pass references of images (and signed manifest) to verification function.
500
Is signed manifest not supplied and authorization check procedure not required ?
YES
Return SUCCESS value.
505
NO
Does manifest digital signature verify using subject public key from certificate[1] of the signed manifest ?
510
NO
Return FAILURE value.
515
YES
Compute hash value of downloaded boot image.
520
Does secure hash value match the hash value ?
525
NO
Return FAILURE value.
530
YES
Is authorization check procedure desired ?
540
NO
Return SUCCESS value.
535
YES
A

Figure 5A

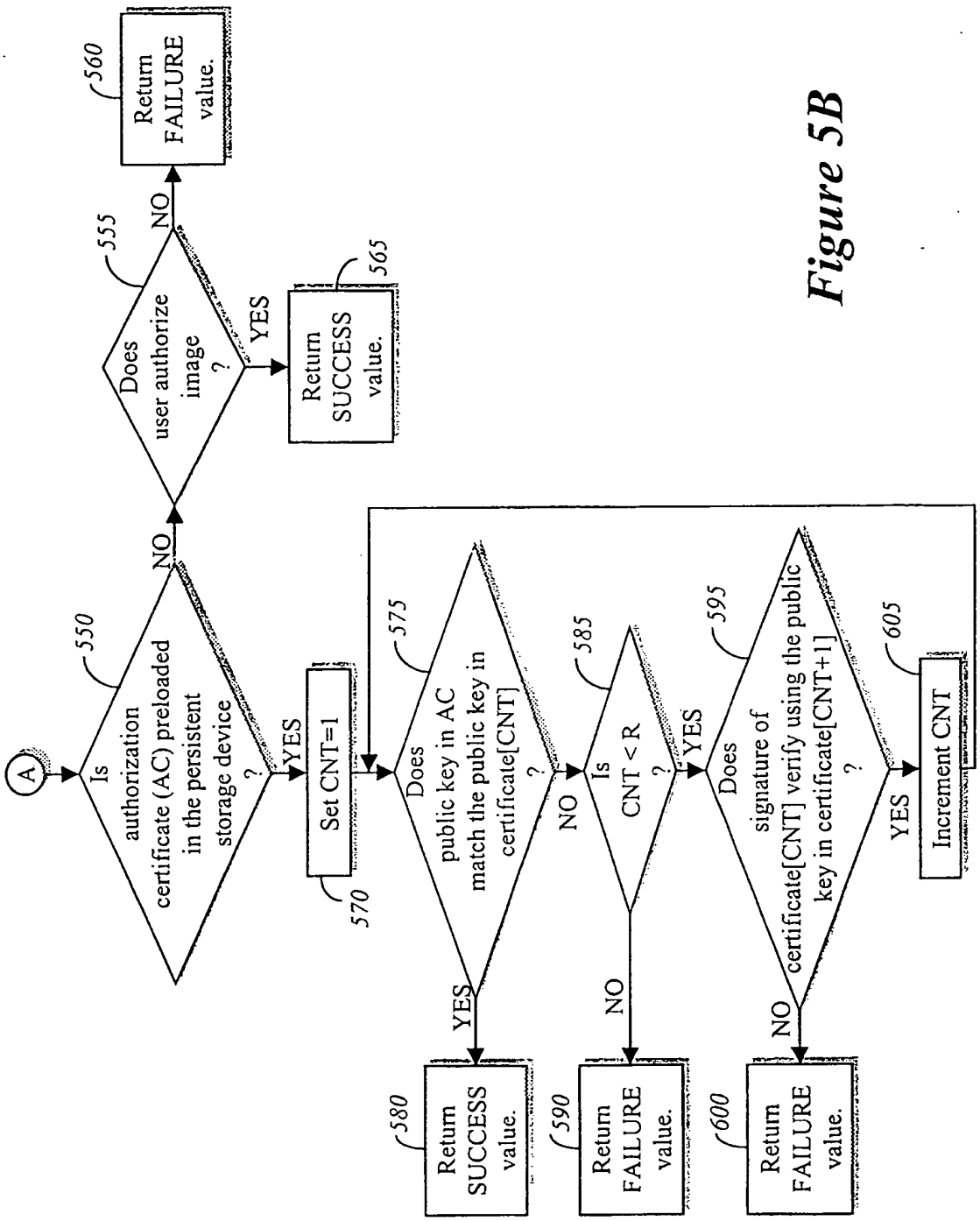
A
Is authorization certificate (AC) preloaded in the persistent storage device ?
550
YES
NO
Set CNT=1
570
Does public key in AC match the public key in certificate[CNT] ?
575
YES
NO
Return SUCCESS value.
580
Is CNT < R ?
585
YES
NO
Return FAILURE value.
590
Does signature of certificate[CNT] verify using the public key in certificate[CNT+1] ?
595
YES
NO
Return FAILURE value.
600
Increment CNT
605
Does user authorize image ?
555
YES
NO
Return SUCCESS value.
565
Return FAILURE value.
560

Figure 5B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/23163

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : H04L 9/00
US CL : 713/201

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 713/1-2, 187-188, 200-201

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WEST ((pre image or preimage) adj4 boot); dialog (inventor name)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	US 5,919,257 A (TROSTLE) 06 July 1999 (06.07.1999), column 2, lines 8-24; column 2, line 43 - column 3, line 18; column 5, line 21 - column 6, line 29; column 6, line 53 - column 7, line 10.	1-10, 14-17
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Y,P		11-13
Y	Schneier, Bruce. Applied Cryptography: Protocols, Algorithms, and Source Code in C. Oct. 1995, pages 574-577.	11-13
A	US 5,349,643 A (COX et al.) 20 September 1994 (20.09.1994), see background; summary; column 6, lines 29-33; column 7, lines 34-41.	1-17
A, P	US 5,935,242 A (MADANY et al.) 10 August 1999 (10.10.1999), see background; column 3, lines 27-40; column 6, lines 21-42; column 7, lines 11-38.	1-17
A	US 5,778,070 A (MATTISON) 07 July 1998 (07.07.1998), column 3, lines 41-57.	1-17

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 November 1999 (30.11.1999)	13 DEC 1999
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230	Authorized officer Gail O Hayes James R. Matthews Telephone No. 703 306 5539

Form PCT/ISA/210 (second sheet) (July 1998)